Decentralized Guidance, Navigation, and Control for Platoons of Cooperating UUVs

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LONG-TERM GOALS

The long-term goals of this project are to develop and implement theoretically justified, yet practical, control algorithms required for deployment of platoons of cooperating unmanned underwater vehicles.

OBJECTIVES

The primary objective of this effort is to develop a methodology for the synthesis of centralized control algorithms that generate multi-objective behaviors for a platoon of vehicles, and may potentially be distributed among a swarm of UUVs. Based on achieved centralized performance, a secondary objective is to generate decentralized versions of these algorithms for a platoon of UUVs with minimal inter-vehicle communication requirements.

APPROACH

Our approach is two-fold. First, we are developing theoretically-justified control algorithms for UUVs and demonstrating their effectiveness via computer simulation. Second, we are building a platoon of very simple and inexpensive ground-based mobile robots for hardware-based verification of our results. Throughout, limited communication constraints are a primary focus.

Our work on control algorithm development is based on the notion of redundant manipulator control [1]. Essentially, a platoon of vehicles carrying out a mathematically described common task can be modeled using techniques from traditional robot control. If there are more total vehicle degrees of freedom than there are task variables in the platoon-level objectives, techniques from redundancy resolution can be applied [2]. A primary control objective is used to define the basic platoon controller, augmented by secondary controllers that are mathematically designed to guarantee that they do not affect the primary task in any way. Essentially, the individual vehicles react to the environment and (potentially) to secondary objectives in a coordinated manner, such that the primary task is unaffected. Secondary controllers and objectives can be designed using methods from traditional system-theoretic control [1] or from behavior-based methods [3]. Figure 1 below shows a sample result for this centralized method, wherein the primary objective is to maintain a specified platoon "mean" (center of mass) and variance along each axis. The vehicles achieve the desired objectives completely while simultaneously avoiding each other and the large obstacle, all with straightforward computation that could be accomplished in real time.

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14. ABSTRACT
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15. SUBJECT TERMS

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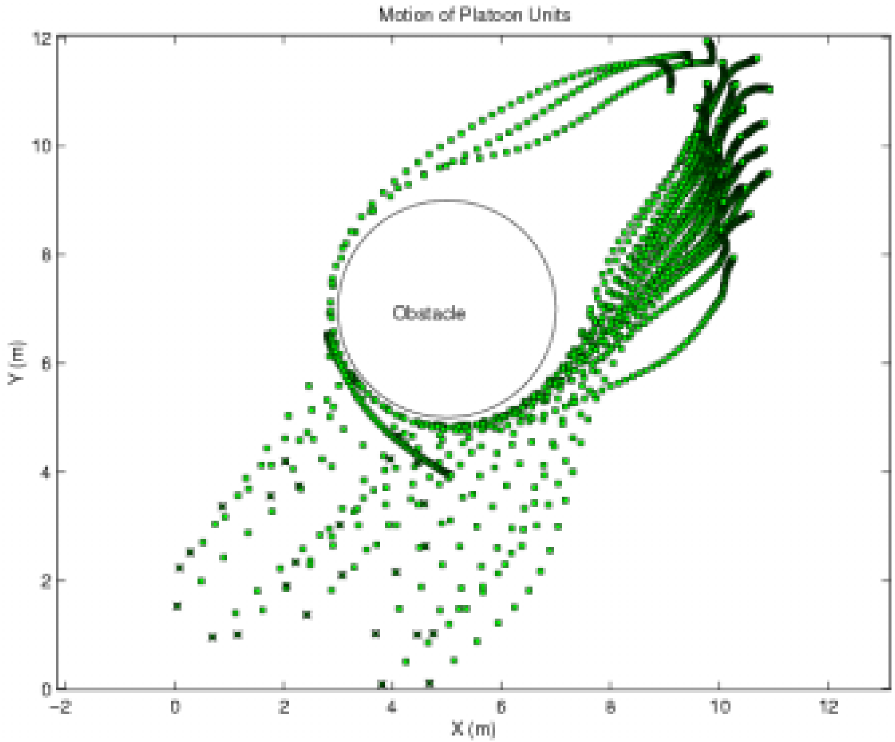

Figure 1. Platoon motion for a platoon of twenty-five vehicles moving with a desired mean and variance through an environment containing a large obstacle. [The individual vehicles move around the obstacle and each other. Simultaneous to each obstacle avoidance maneuver, the rest of the platoon responds to guarantee that the mean and variance match the desired profile at all times.]

Implementation of this method for control requires addressing fundamental issues in robot mobility, sensing and communication. The design of controllers for nonholonomic vehicles requires careful analysis and development of a new set of tools to augment the primary controller. These tools will be based on kinematic analysis and behavior-based methods in robotics.

The very promising methods developed using this fundamentally new formulation of the platoon formation synthesis problem are to be addressed from a decentralized standpoint. Analysis of communication burden forms the fundamental core of the process, and is based on our original work on decentralization using the concept of decentralized fixed modes [4], [5]. Under this approach, we are able to propose a candidate communications network and determine if a stabilizing controller exists that can be decentralized among vehicles in a platoon. We can evaluate the minimum communications for a proposed network and objective function using these techniques. For example, we have examined the network topology shown in Figure 2 and shown that the total communications bandwidth is independent of the number of vehicles in the platoon. This property permits platoons composed of larger numbers of vehicles to be controlled despite the limited underwater communication channel. Details of this network and related networks are available in [6] and [7].

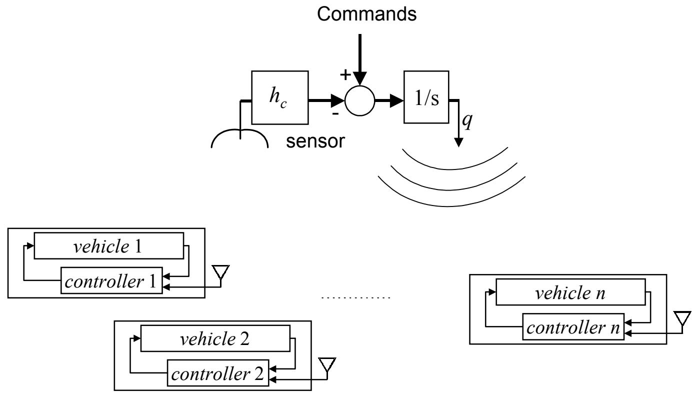

Figure 2. Block-diagram of a communications network topology for a platoon of UUVs. [An exogenous sensor is shown along with a platoon of UUVs. The exogenous sensor measures features of the platoon that are to be regulated, integrates the measurements, and broadcasts them to the platoon. Each vehicle implements a local controller whose inputs are locally generated information and the signal broadcast from the exogenous sensor.]

WORK COMPLETED

We have generated a complete, real-time architecture for casting the platooning problem, based on techniques from redundant manipulator control. Through a straightforward decoupling technique, we have shown that the redundancy-based methods for control of platoon mean and variance are easily decentralized. The resulting communication requirement matches that predicted by our existence tests, and the synthesis technique is extremely straightforward. This is significant progress, as the synthesis methodology was the most difficult aspect of decentralization in our previous work. This result demonstrates that the redundancy-based approach is intuitive, appealing from both system-theoretic and behavior-based standpoints, and provides a straightforward means for decentralization.

Acquisition of components for ground-based hardware experiments is complete, and integration of these components for testing of the results on decentralized redundancy-based methods has begun. The system is based on nonholonomic vehicles called ARobots (see Figure 3), a panoramic camera and radio modems. MIDN 1/C Brian Sofen of the United States Naval Academy has taken the lead in performing these experiments as part of his program of study for the Systems Engineering degree.

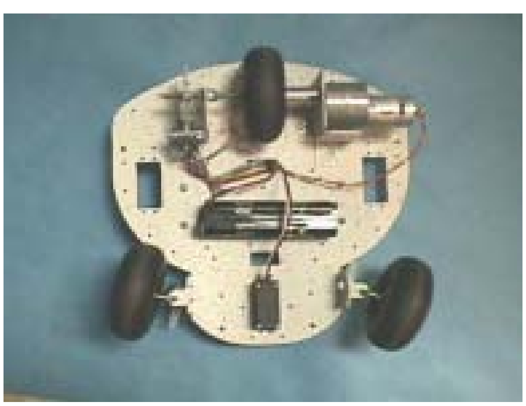

Figure 3. The ARobot is a nonholonomic three-wheeled vehicle with two steered and undriven wheels and one unsteered but driven wheel.

RESULTS

The development of a fundamentally new, real-time platoon formation synthesis controller forms the heart of the results to date [2]. Decentralization of this controller has been shown to be possible in a straightforward manner with minimal communication bandwidth for the given network topology.

These results have significance in that they allow for a systematic design of a provable, real-time path planning and platoon formation synthesis procedure for cooperating vehicles using limited communication bandwidth. The proposed architecture can be easily decomposed into a hierarchical scheme (wherein platoons of platoons perform macro-scale functions) based on available sensing and communication range.

Further, we note that the method of casting the platoon formation synthesis problem addresses a fundamental issue in platoon control. Almost every existing method for platoon formation control takes as a predicate the exact formation or some topology thereof. This technique allows mathematically defined functions of the platoon to be achieved while simultaneously carrying out secondary objectives, allowing development of the platoon formation based on environmental interaction and the full set of objectives. Without explicit planning, the platoon will automatically adjust to account for the current environment and the current set of tasks without a large computational burden.

Finally, it is significant that the synthesis of decentralized controllers, even with the knowledge that such exist for a given system, is a challenging problem in general [8]. The straightforward method for generating decentralized controllers for the proposed approach is therefore a strong benefit of the architecture.

IMPACT/APPLICATIONS

This work has broad applicability in the field of autonomous robotic vehicles. Our work on centralized techniques has applicability for networked vehicle platoons and offers a new perspective on the cooperation, formation synthesis and planning problems. Decentralized techniques are fundamental to efficient utilization of multiple vehicle deployments, especially in the underwater theatre where communication is a substantial bottleneck. Indeed, many algorithms designed for ground and air applications are not applicable underwater due to communication constraints. Further, limiting bandwidth required for a particular objective allows for a maximal number of units to operate in a platoon and thereby increases survivability and functionality.

TRANSITIONS

None to date.

RELATED PROJECTS

None.

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